LABORATORY SAFETY

Laser Laboratories
IESL-FORTH

D. Anglos
02/08/2016

LABORATORY SAFETY

- **LASER RADIATION**
- **ELECTRICAL HAZARDS**
  High voltage, Regular power και UPS
- **CHEMICALS**
  GASES (Gas tanks)
  LIQUIDS (Acids/Alkali, Organic solvents)
  SOLIDS
  WASTE
- **VARIOUS**
  Water supply
  Continuously operating equipment

Example of eye damage

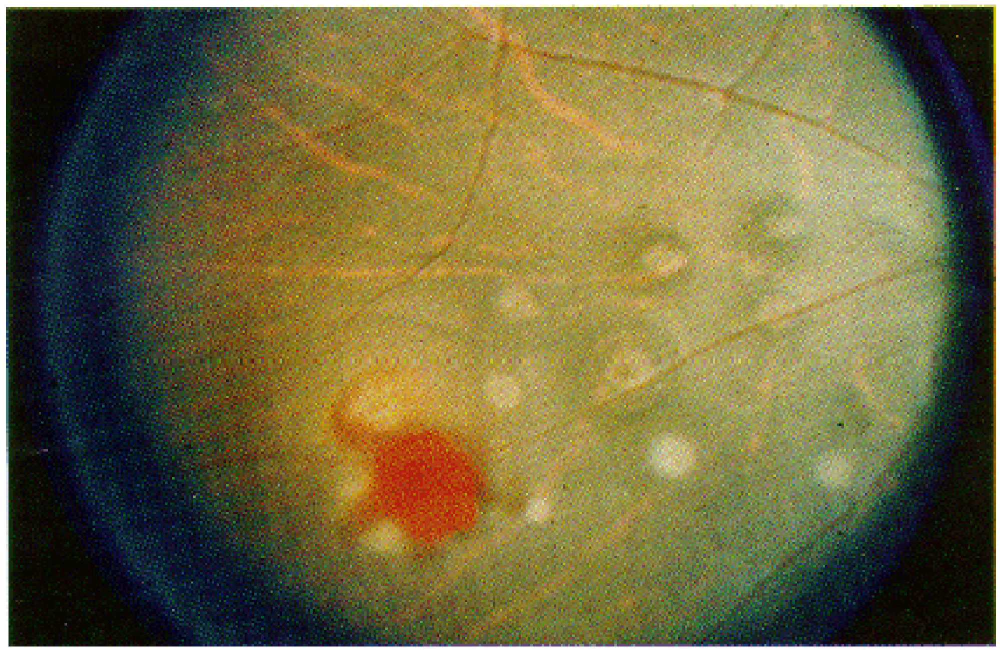


Figure 7. Multiple small laser burns with minimal hemorrhage.

http://www.adtdl.army.mil/cgi-bin/atdl.dll/fm/8-50/INTRO.htm

Question

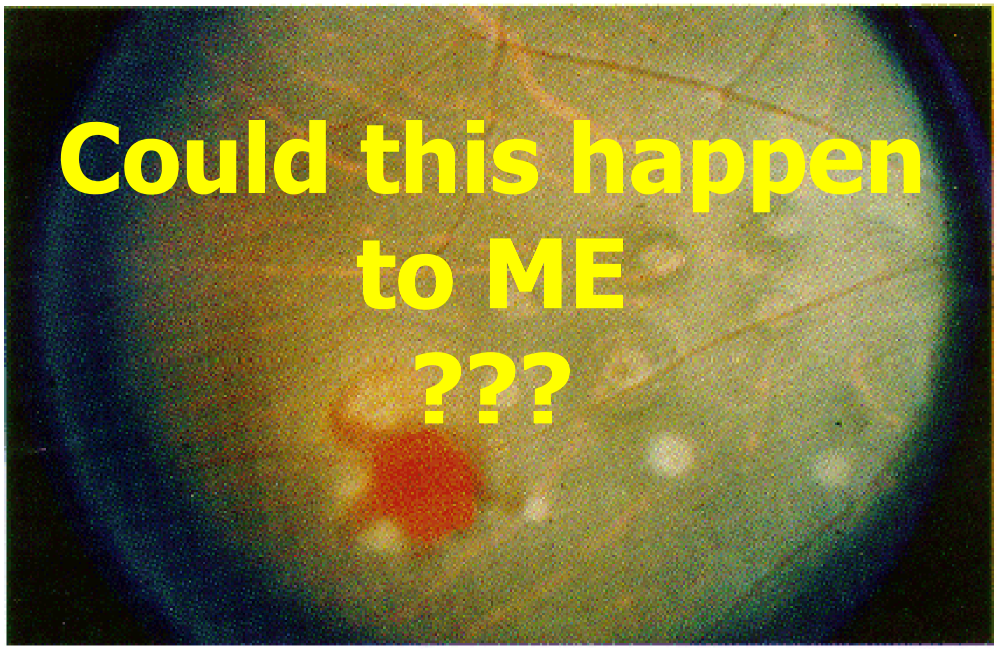


Figure 7. Multiple small laser burns with minimal hemorrhage.

http://www.adtdl.army.mil/cgi-bin/atdl.dll/fm/8-50/INTRO.htm

255: Beam blinds scientist doing alignment of a Nd:YAG laser

During optics alignment involving a 30 mJ pulsed Nd:YAG laser (10 Hz) on a target using a prism, the beam exceeded the prism's critical angle and struck the scientist in the eye resulting in a permanent retinal burn.

Unfortunately, no protective eyewear was worn at the time.

An ophthalmologist was consulted and confirmed retinal burns.
Blurry vision resulted especially when reading.

http://www.rli.com/accident/case_studies/

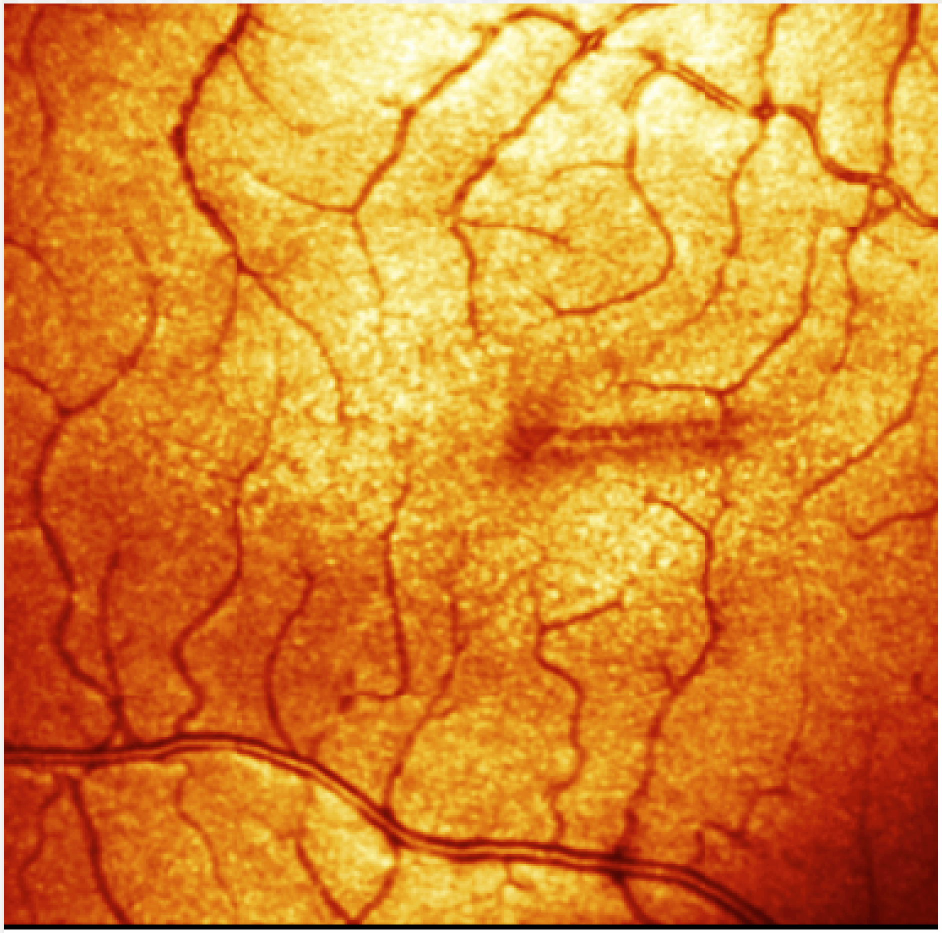
307: Backscatter from mirror causes hemorrhage and foveal blindspot

A 26 year old male student aligning optics in a university chemistry research lab using a "chirped pulse" Titanium-Sapphire laser operating at 815 nm with 1.2 mJ pulse energy at 1 kHz. Each pulse was about 200 picoseconds. The laser beam backscattered off REAR SIDE of mirror (about 1% of total) caused a foveal retinal lesion with hemorrhage and blind spot in central vision.
A retinal eye exam was done and confirmed the laser damage.

The available laser protective eyewear was not worn.

http://www.rli.com/accident/case_studies/

---: Backscatter from metal mirror-like surface causes multiple spots at the fovea



1st TAKE Safety ACTION

Incident ALERT Message from Performance Surety

FOR DETAILS:
- **Occurrence Report:** ALO-LA-LANL-CHEMLASER-2004-0001
- **PS-7 Occurrence Investigators:** Matt Hardy, 667-6335; Rita Henins, 665-6981

An additional alert about this event will follow if the investigation reveals details that indicate an unknown hazard exists for other employees involved in this type of activity. For more information about "1st Take," please call LANL PS-7 at 665-0033.

August 18, 2004
LANL CHEMLASER 2004-0010

Student sustains laser eye injury

On July 14, 2004, an undergraduate student employed by another government agency was injured while performing work with a Class IV neodymium (Nd): YAG laser at Los Alamos National Laboratory. The student came to the Laboratory to work with a LANL scientist investigating the potential use of lasers in studying the composition of comets.

The scientist and student had set up a laser experiment designed to suspend and then analyze particles inside a vacuum target chamber using an unusual configuration that was neither described nor analyzed in work control documents. The experiment used a Particle Generating (PG) laser to suspend the particles and the (Nd:YAG) Laser Induced Breakdown Spectroscopy (LIBS) laser to vaporize the suspended particles. The PG laser was aligned vertically to allow the beam to enter through the top of the target chamber; the LIBS laser was aligned horizontally to allow the beam to enter through a side window. The scientist energized both laser power supplies and was operating the LIBS laser with the Q switch trigger cable disconnected (a mode the scientist believed did not allow the LIBS laser to produce a laser beam). With the Q switch disabled and the LIBS laser's flashlamps operating, the scientist believed that only white light exited the laser's optical tube and traveled down the laser beam path. The scientist wanted to demonstrate that the PG laser could suspend particles from the sample and intended to use the light from the LIBS laser to illuminate the suspended particles and make them visible inside the target chamber.

Experimental setup showing the target chamber and the LIBS laser

Re-creation of target viewing position

The scientist fired and secured the PG laser and then observed the suspended particles illuminated by the LIBS laser inside the target chamber. He told the student he could see suspended particles and invited the student to take a look. As the student bent down to look into the chamber, she saw a flash and subsequently noted a reddish brown substance floating in her left eye. Neither the scientist nor the student were wearing laser eye protection. The student was taken to LANL's occupational health facility (HSR-2) and was referred to several eye specialists. Laser eye damage was confirmed. The student continues to experience loss of central vision in her left eye.

Laser operations were suspended and the LANL Director assembled a team to investigate the accident, determine the causal factors, and make recommendations.

Initial Analysis

The investigation is nearing completion and formal findings will be made available in a few weeks after corrective actions are developed and incorporated. Lines of inquiry have included the use of personal protective equipment, the mentoring and supervision of students, management oversight and control of work/workers, and the reporting and notification process for abnormal events. Laboratory measurements were made to characterize the conditions and configuration believed to have existed when the accident occurred. Measurements indicated that the student could not have received a laser eye injury under these conditions because the LIBS laser did not emit a beam in this configuration. Consequently, the team is evaluating if other configurations could have resulted in the accident.

Initial Recommendations

Management Level: Managers should:
- Ensure that required safety practices are implemented in the workplace;
- Ensure training requirements are completed before authorizing work;
- Ensure that personal protective equipment is used;
- Ensure laser personnel complete a baseline eye examination;
- Ensure changes to work and associated changes in work configuration are authorized, and that these changes are addressed in work control documents; and
- Provide LANL employees with this "1st Take," either through Nested Safety meetings or required reading programs.

Worker Level: Workers should:
- Know the hazards of their experiment;
- Wear specified laser eye protection as required;
- Challenge unsafe or questionable behavior, and if you're not sure, *ask*;
- Use interlocks as designed; and
- Prevent eye exposure to direct or scattered radiation from a Class IV laser.

More information will be provided to employees in the "Final Take" alert message from Performance Surety.

GUIDANCE: Resources at hand

For more information related to laser safety you can refer to:
- Lasers LIR 402-400-01.3
- Laser Safety: Class 3b or 4 Self Study Course No. 17817
- American National Standards Institute Z136.1 (Safe Use of Lasers)
- Lessons Learned: Operational Experience Summaries, 2nd Quarter - 2004 (http://www.eh.doe.gov/paa)
- Occurrence Report: ALO-LA-LANL-CHEMLASER-2004-001
- Occurrence Report: OAK-LBL-MSD-2003-0001
- Occurrence Report: ALO-LA-LANL-FIRNGHELAB-1999-0002
- Occurrence Report: ALO-LA-LANL-FIRNGHELAB-1998-0002

Experimental setup showing the target chamber and the LIBS laser

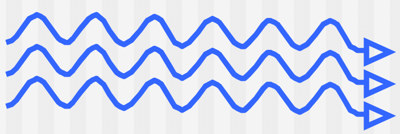
Re-creation of target viewing position

LASER SAFETY

- **Laser sources**
- **Laser hazards**
- **Interaction of laser radiation with biological tissues**
- **Prevention - Protection**

LASER SOURCES

- Solid state
- Gas lasers
- Excimer
- Dye lasers
- Diode lasers



Coherence,
Monochromaticity,
Directionality

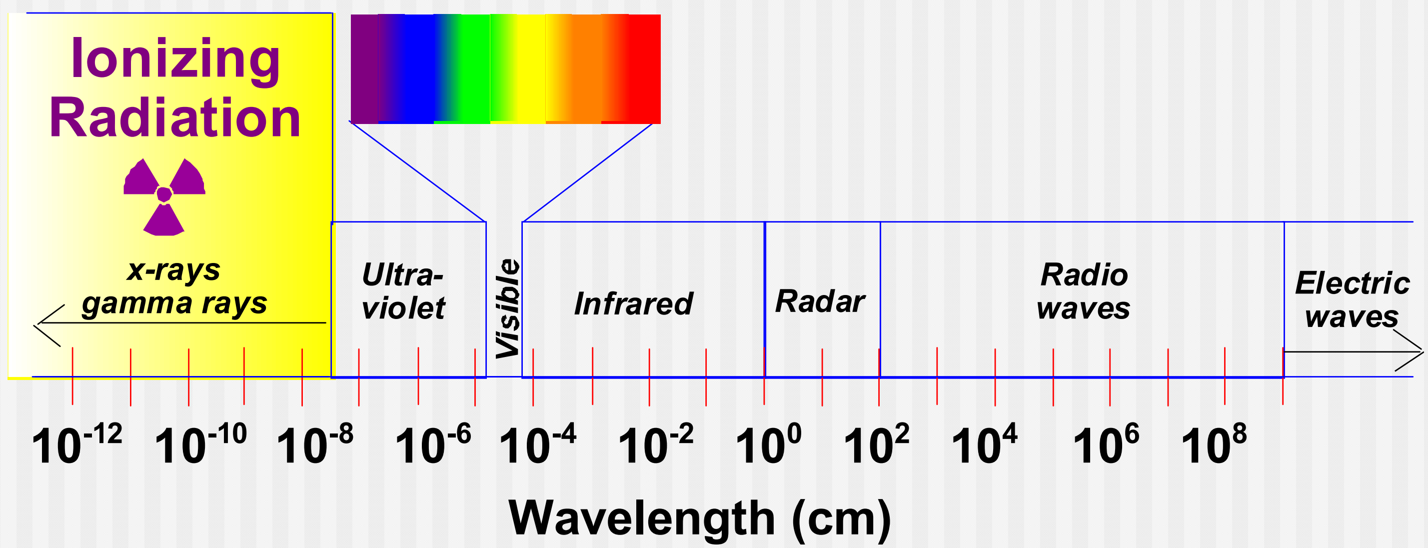
LASER RADIATION

Spectral range

Band		Wavelength
Ultraviolet (UV)	**UV-C**	**200 – 280 nm**
	UV-B	**280 – 315 nm**
	UV-A	**315 – 400 nm**
Visible (VIS)		**400 – 700 nm**
Infrared (IR)	**IR-A**	**700 – 1400 nm**
	IR-B	**1400 – 3000 nm**
	IR-C	**3000 – 1 mm**

LASER PARAMETERS I

- Emission wavelength (UV, Visible, IR)
- Output power/energy (mW-W, nJ-kJ)
- Pulse duration (cw, ns, ps, fs)



LASER PARAMETERS II

Radiant Power: P (W)

Radiance : $L = P / A\,\Delta\Omega$ ($W/cm^2 sr$) A : source area

Radiant energy density : ρ (J/m^3)

Spectral power density: $P(\nu)$ (W/Hz)

Brightness : $\beta_\nu = P(\nu) / A\,\Delta\Omega\,\Delta\nu$ ($W/cm^2 srHz$)

Intensity : $I(\nu) = P(\nu) / A\,\Delta\nu$ ($W/cm^2 Hz$)

Sun : β(580 nm; 5800 K) ≈ 1,5x10-12 $W/cm^2 srHz$

He-Ne laser, P=1 mW

β(632,8 nm; $\Delta\nu$=1x104 Hz) ≈ 25 W/cm2 sr Hz

LASER PARAMETERS II

Laser pulse energy : $E = \int P(t)dt$ (J)

Laser pulse peak power) : $P = E/\Delta\tau$ (W)

$\Delta\tau$: temporal pulse width (FWHM)

Irradiance, Power density) : $I = P/A$ (W/m^2)

Energy density (flux) : $F = E/A$ (J/m^2)

A : irradiated area

LASER CLASSES

- **CLASS 1** harmless
- **CLASS 2** visible radiation
momentary exposure (0.25s)
- **CLASS 3** 3a (1 – 5 mW)
3b (5- 500 mW)
no direct exposure
- **CLASS 4** Pulse or cw (>500 mW)
Extremely hazardous

Class 1 Lasers

Class 1 lasers do not emit harmful levels of radiation .

Class 2 Lasers (< 1mW, commonly found in alignment applications)

Capable of creating eye damage through chronic exposure. In general, the human eye will blink within 0.25 second when exposed to Class 2 laser light, providing adequate protection. It is possible to stare into a Class 2 laser long enough to cause damage to the eye.

Class 2a Lasers (special purpose < 1mW, e.g. barcode readers)

Class 3a Lasers (1-5 mW)

Not hazardous when viewed momentarily with the naked eye, but they pose severe eye hazards when viewed through optical instruments (e.g., microscopes and binoculars).

Class 3b Lasers (5-500 mW or less than 10 J/cm^2 for a ¼-s pulsed system)

Injury upon direct viewing of the beam and specular reflections. Specific control measures must be implemented.

Class 4 Lasers (> 500 mW or greater than 10 J/cm^2 for a ¼-s pulsed system)

They pose eye hazards, skin hazards, and fire hazards. Viewing of the beam and of specular reflections or exposure to diffuse reflections can cause eye and skin injuries. All control measures to be outlined must be implemented.

HAZARDS FROM USING LASER

-**Laser radiation**

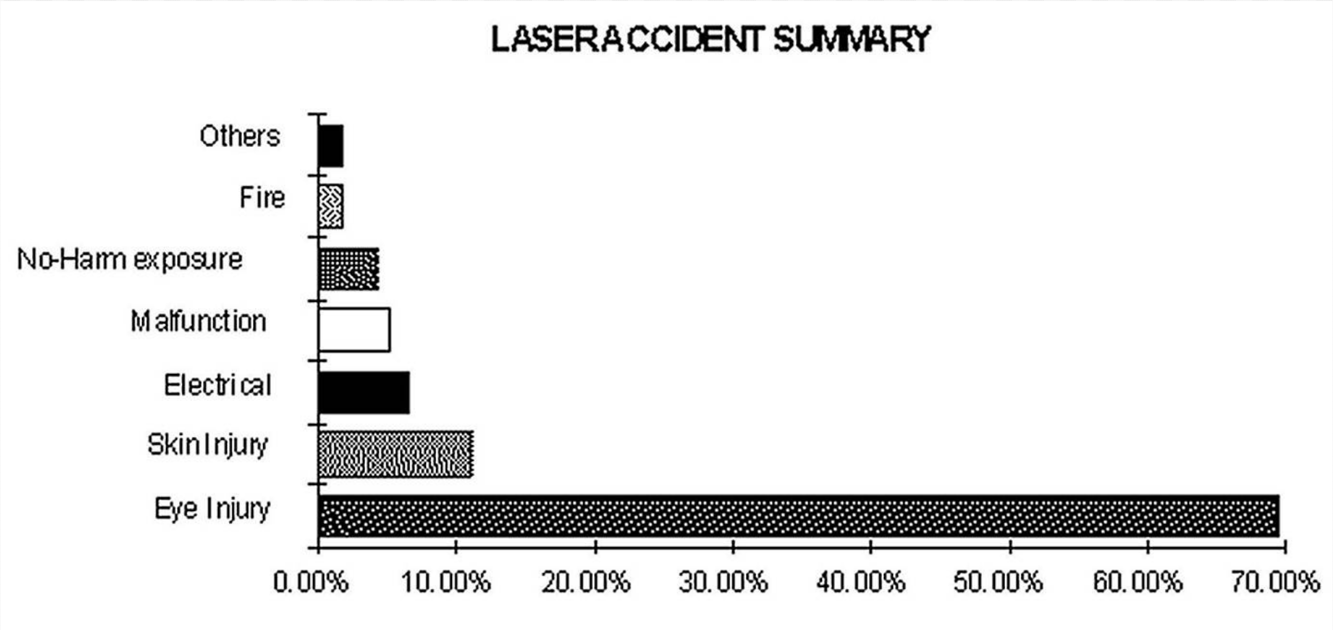
- eye injury, damage
- skin injury (burn)

- **Other**

- electrical power supply
- toxic chemicals, solvents (dye lasers)
- toxic gases (excimer lasers)
- fire
- secondary radiation
- plasma radiation
- excessive noise

LASER ACCIDENTS (1)

Laser accidents (USA, 1964-1992)

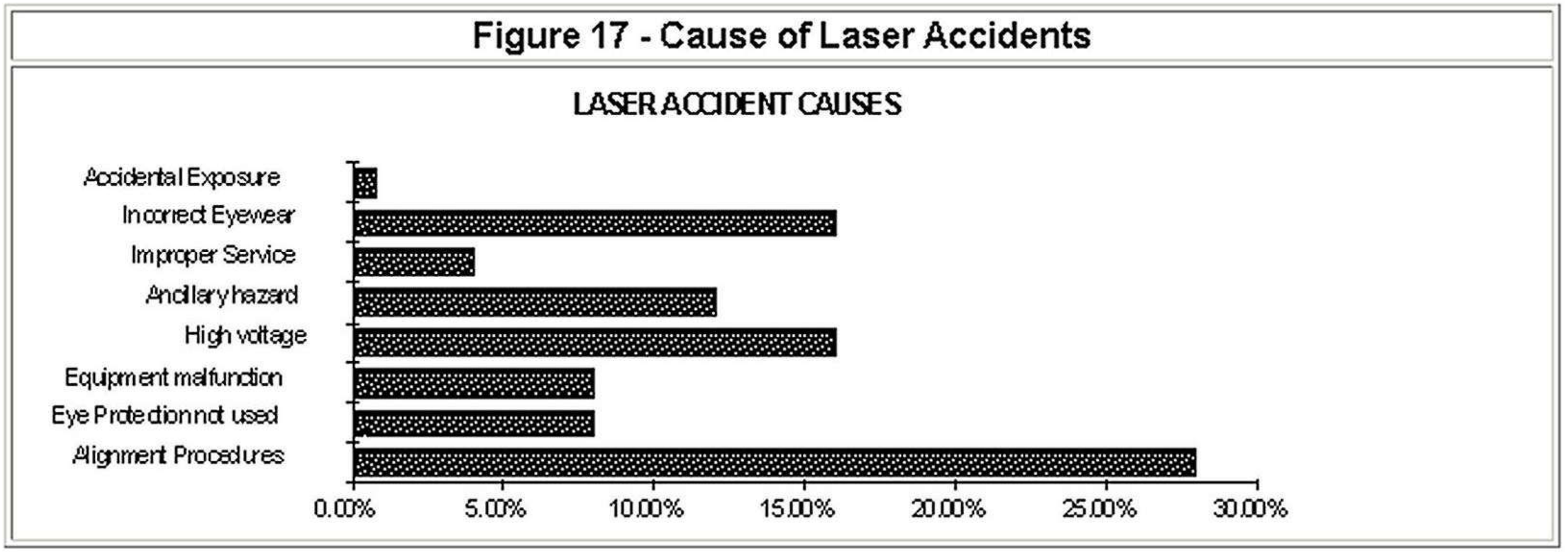


Most accidents involve eye injuries

http://www.adm.uwaterloo.ca/infohs/lasermanual/documents/section11.html

LASER ACCIDENTS (2)

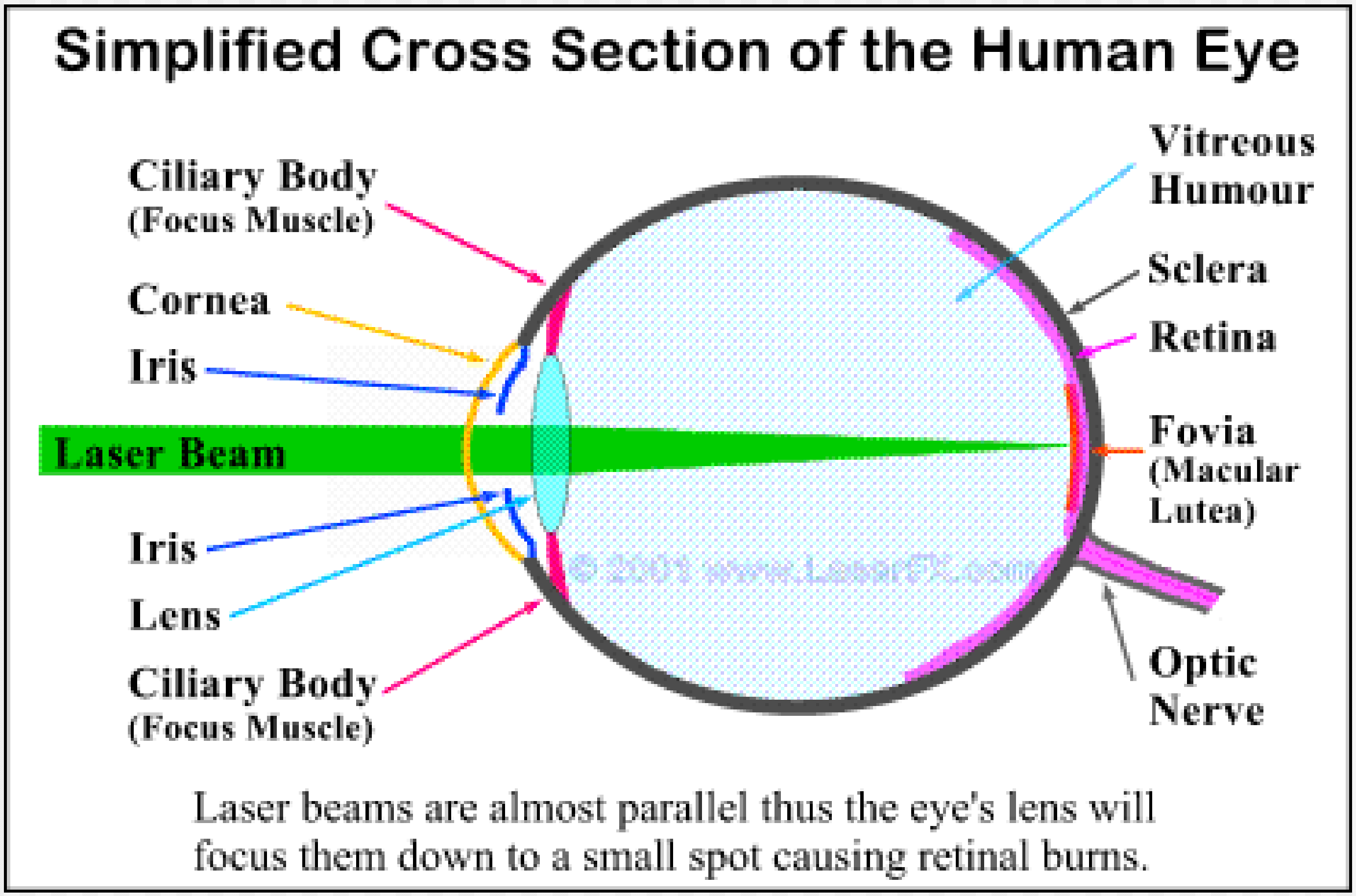
Cause of Laser accidents (HПА, 1964-1992)



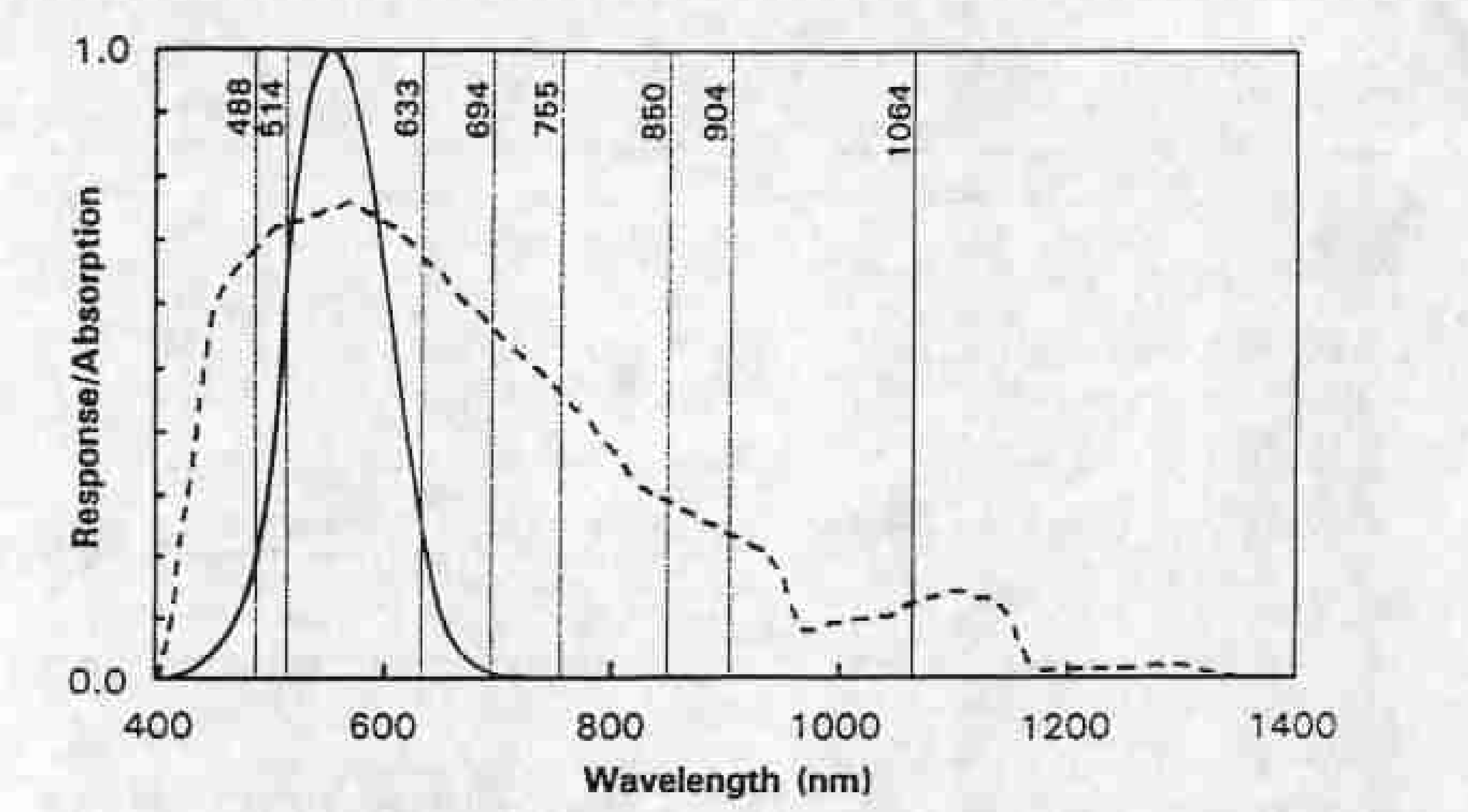
Most accidents take place during beam alignment or/and because no proper eyeware was used

http://www.adm.uwaterloo.ca/infohs/lasermanual/documents/section11.html

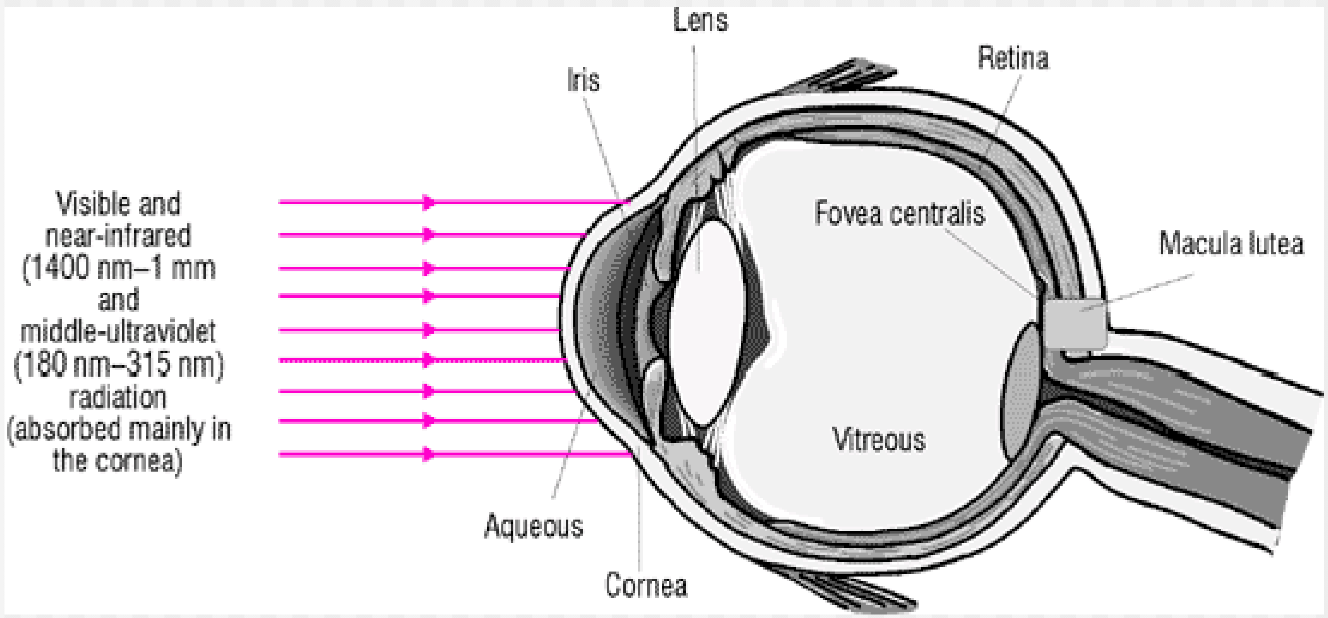
THE HUMAN EYE



OPTICAL RESPONSE AND TRANSMISSION OF THE HUMAN EYE



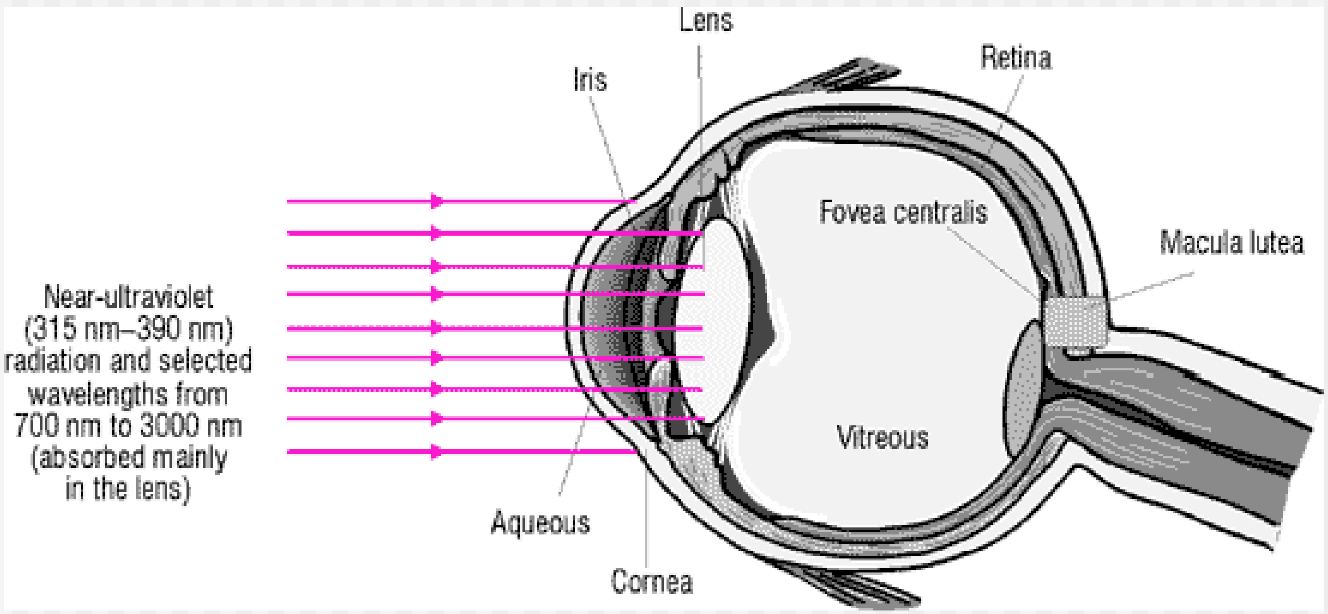
Absorption of radiation by the eye



Mid- and Far-Infrared (1400 nm – 1mm)
Mid-Ultraviolet (180 nm –315 nm)

Absorption at the cornea

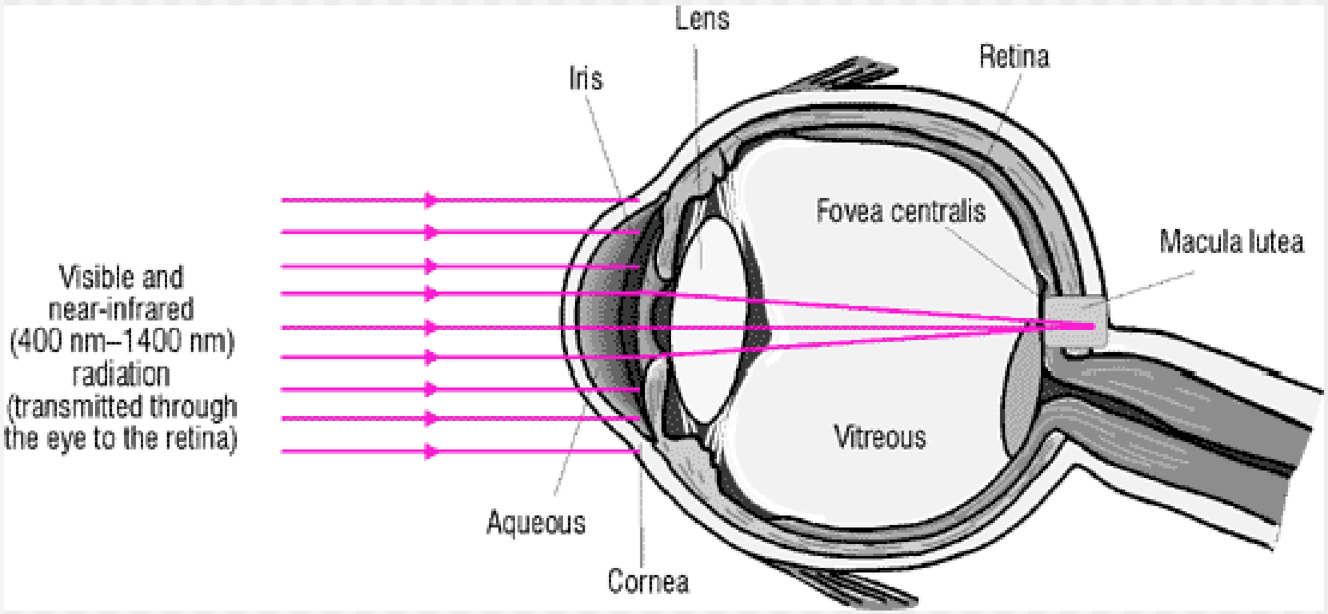
Absorption of radiation by the eye



Near-Ultraviolet (315 nm – 390 nm)
Selected wavelengths in 700 nm – 3000 nm)

Absorption at the lens

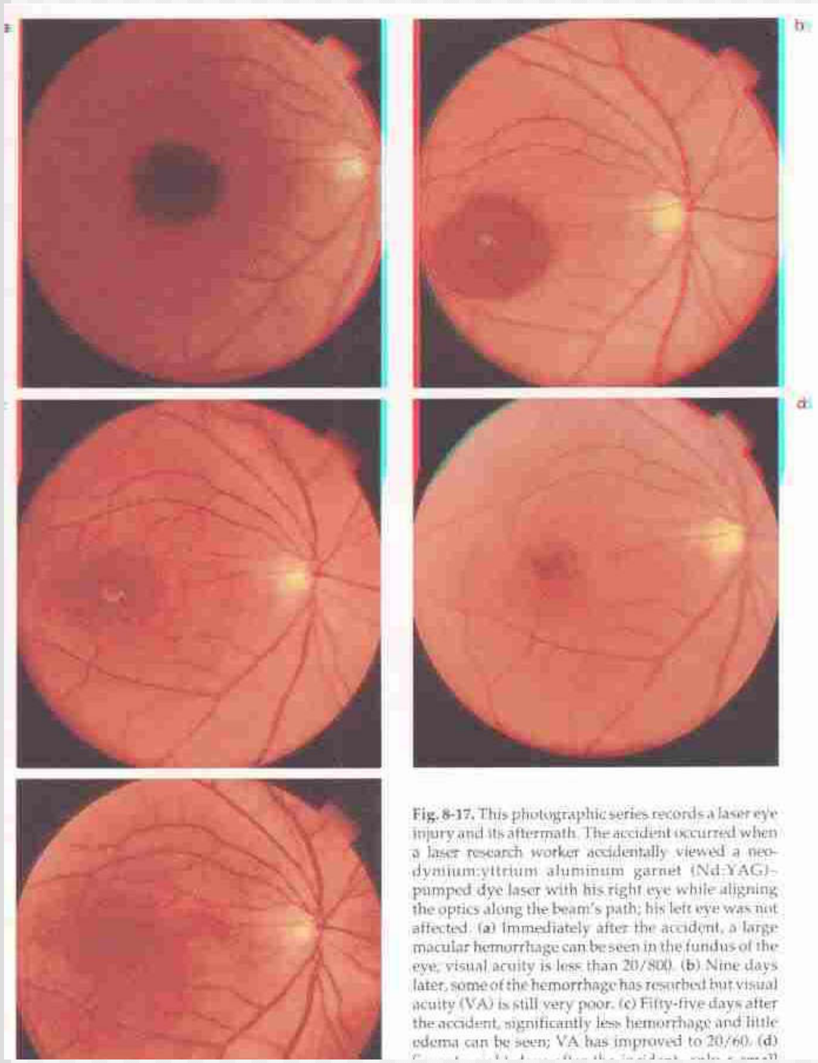
Absorption of radiation by the eye



Visible and Near-Infrared (400 nm – 1400 nm)

Radiation focuses on retina

EXAMPLE OF EYE INJURY



Accidental exposure to beam from pulsed dye-laser

Day 1
Macular hemorrhage developed in the eye fundus.
Visual acuity (VA) <20/800

Day 9
Significant hemorrhage, very poor VA

Day 55
Less hemorrhage, improved VA (20/60)

Day 78
Small pocket of hemorrhage VA (20/30)

Day 177
Eye almost normal

ΠΑΡΑΔΕΙΓΜΑ

Small fraction (4%) of pulsed laser beam, diameter 2 mm, with energy of 2.5 mJ/pulse, reflected from a piece of optic has energy density of :

$$(10^{-1}\ mJ)/(0.25 \times \pi \times (0.2)^2\ cm^2) = 3.2\ 10^{-3}\ J/cm^2$$

This exceeds the damge threshold of the cornea ($\sim 10^{-7}$ J/cm^2) by a factor of $3.2\ 10^4$.

Protection for this level of exposure requires the use of appropriate laser eye-ware with optical density at the laser wavelength :

$$(OD) = \log(3.2\ 10^4) = 4.5$$

TISSUE DAMAGE MECHANISMS

- Thermal effects (burns)
- Photochemical alterations
- Acoustic shock waves

Photobiological spectral domain	*Eye effects*	*Skin effects*
Ultraviolet C (0.200-0.280 μm)	Photokeratitis	Erythema (sunburn) Skin cancer
Ultraviolet B (0.280-315 μm)	Photokeratitis	Accelerated skin aging Increased pigmentation
Ultraviolet A (0.315-0.400 μm)	Photochemical UV cataract	Pigment darkening Skin burn
Visible (0.400-0.780 μm)	Photochemical and thermal retinal injury	Photosensitive reactions Skin burn
Infrared A (0.780-1.400 μm)	Cataract, retinal burns	Skin burn
Infrared B (1.400-3.00 μm)	Corneal burn Aqueous flare IR cataract	Skin burn
Infrared C (3.00-1000 μm)	Corneal burn only	Skin burn

PREVENTION - PROTECTION

The use of proper safety eyeware is mandatory in the laser laboratory

PREVENTION - PROTECTION

LASER SAFETY RULES

- **No access of un-authorized personnel in the laboratory**
- **Special safety seminar mandatory before working in the laboratory**
- **Use of proper safety eyeware is mandatory in the laboratories**
- **During alignment and during experiments take all possible precautions to prevent direct or indirect exposure of anyone in the laboratory to laser radiation**
- **Special caution to UV and IR radiation**
- **All of us have to adopt the rules of good laboratory practice**

LASER SAFETY RULES

Proper labeling of lasers and laboratories

Warning light for laser operation

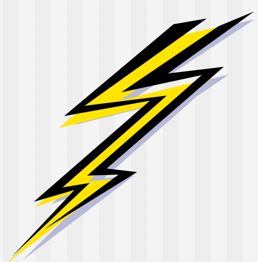
LABORATORY SAFETY

- **LASER RADIATION**
- **ELECTRICAL HAZARDS**
  High voltage, Regular power και UPS
- **CHEMICALS**
  GASES (Gas tanks)
  LIQUIDS (Acids/Alkali, Organic solvents)
  SOLIDS
  WASTE
- **VARIOUS**
  Water supply
  Continuously operating equipment

ELECTRICAL HAZARDS

- High voltage
- Regular power and UPS

Class3 and Class 4 lasers have high-voltage power supplies or sub-units (1-10 kV)



CHEMICALS

- GASES

  Toxic or inert gases are kept in special gas tanks (experiments, excimer lasers)

- LIQUIDS

  Acids/Alkali, Chemical reagents, Organic dyes

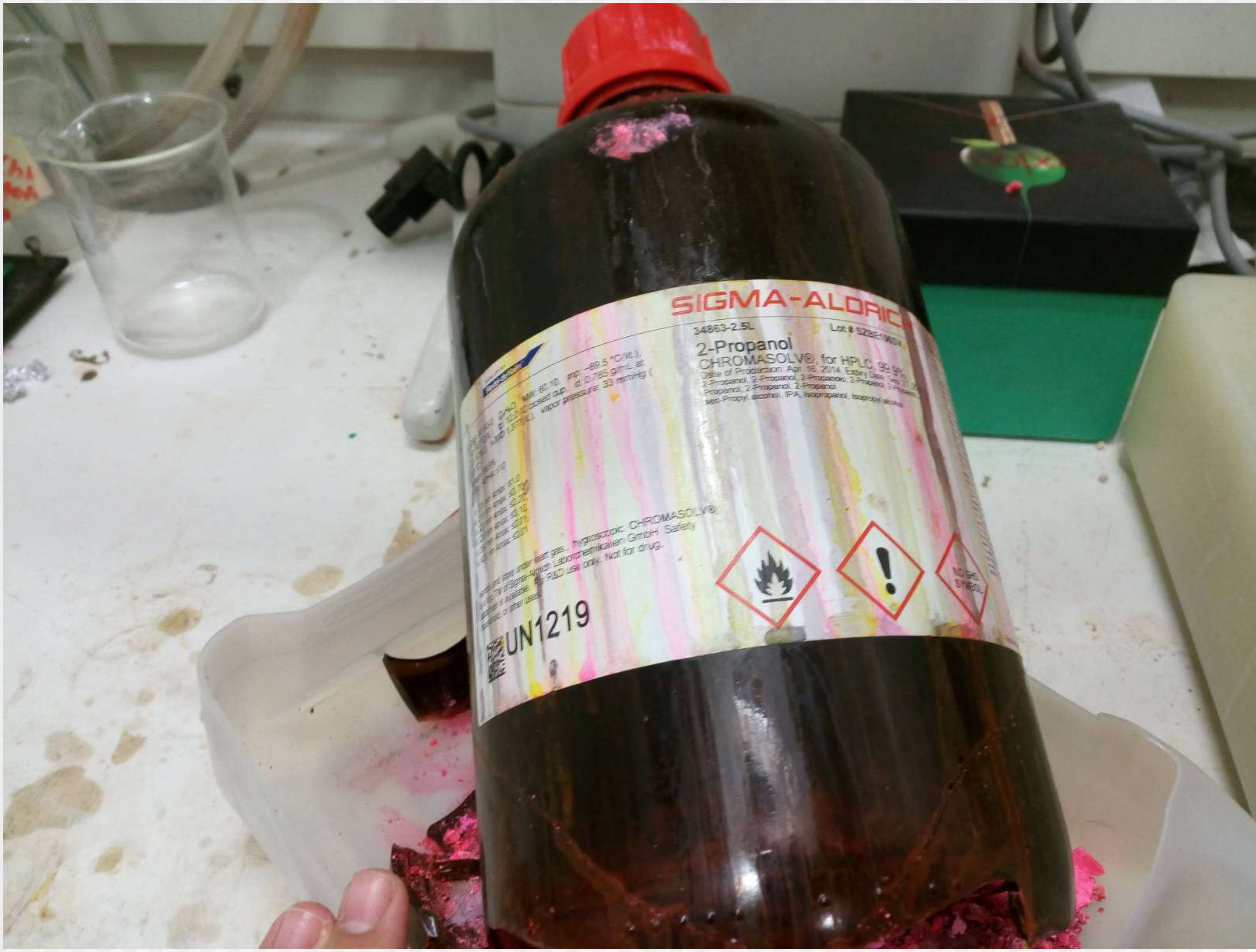
- SOLIDS

- WASTE DISPOSAL

CHEMICALS

CHEMICALS

CHEMICALS


SIGMA-ALDRIC
34863-2.5L
2-Propanol
CHROMASOLV®, for HPLC, 99.9%
UN1219

VARIOUS

- FIRE

  Short circuits (<u>CAUTION</u> power cables)

  Laser (Ignition of plastic, wood, clothing materials)

- WATER SUPPLY

  <u>CAUTION</u> cooling water pipes

- CONTINUOUSLY OPERATING EQUIPMENT

LABORATORY CARD

ΕΡΓΑΣΤΗΡΙΟ : B-207

ΥΠΕΥΘΥΝΟΣ ΕΡΓΑΣΤΗΡΙΟΥ : Α. Εγγλέζης
Τηλέφωνο : -1327(γρ), 2810-318765(σπ),

ΥΠΕΥΘΥΝΟΣ ΑΣΦΑΛΕΙΑΣ : Δ. Αγγλος (D. Anglos)
Τηλέφωνο : -1154 (γρ), 2810-235392 (σπ), 693 7748630 (κιν)

Τηλέφωνα άμεσης ανάγκης – Call for Emergency

Τεχνική Υπηρεσία	-1094, -1095	Building service
Πύλη ΙΤΕ (Φύλάκας)	-1111	FORTH gate
Πυροσβεστική	199*	Fire Department
Αστυνομία	100*, 2810-282316*	Police
ΕΚΑΒ	166*	
ΠΕΠΑΓΝΗ	2810-392111*	University Hospital
Βενιζέλειο	2810-237502*	Venizelio Hospital

* Για εξωτερική γραμμή πρώτα το 9 (Dial 9 to get an outside line)

ACCIDENT REPORT

Ονομα – Επώνυμο	**:**	
Ιδιότητα (Ερευνητής, φοιτητής)	**:**	
Ημερομηνία	**:**	
Εργαστήριο	**:**	
Επιστημονικός Υπεύθυνος	**:**	
Είδος ατυχήματος :		Τραυματισμός Υλικές ζημιές Φωτιά
Πηγή ατυχήματος :		Λέιζερ Ηλεκτρική τροφοδοσία Χημικά Τροφοδοσία νερού

LABORATORY SAFETY

- **LASER RADIATION**
- **ELECTRICAL HAZARDS**
  High voltage, Regular power και UPS
- **CHEMICALS**
  GASES (Gas tanks)
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  SOLIDS
  WASTE
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  Water supply
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LASER PARAMETERS II

Ισχύς ακτινοβολίας (Radiant Power): P (W)

Radiance : $L = P / A\,\Delta\Omega$ (W/cm2 sr) A : διατομή πηγής

Πυκνότητα ενέργειας (Radiant energy density) : ρ(J/m3)

Φασματική πυκνότητα ισχύος (Spectral power density): P(ν) (W/Hz)

Λαμπρότητα (Brightness) : $\beta\nu = P(\nu) / A\,\Delta\Omega\,\Delta\nu$ (W/cm2 sr Hz)

Φασματική ένταση (Intensity) : $I(\nu) = P(\nu) / A\,\Delta\nu$ (W/cm2 Hz)

Ηλιος : β(580 nm; 5800 K) ≈ 1,5x10-12 W/cm2 sr Hz

Λέιζερ He-Ne, P=1 mW β(632,8 nm; Δν=1x104 Hz) ≈ 25 W/cm2 sr Hz